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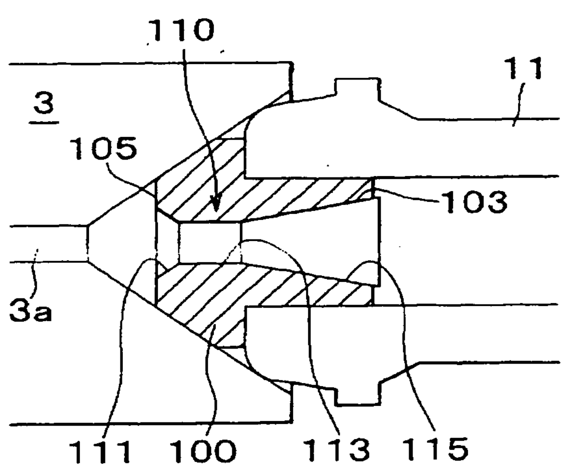
(54) Fuel injection apparatus

(57) Orifice pieces (100) are disposed in connecting portions between a common rail (3) and high-pressure fuel pipes (11) that supply high-pressure fuel to fuel injection valves (10a-10d). Each orifice piece (100) has, in its interior, a fuel passage that is formed by an inlet-side taper portion (111), a small-diameter constricted portion (113), and an outlet-side taper portion (115). The inclination angle of a wall surface of the outlet-side taper portion (115) is set smaller than the inclination angle of a wall surface of the inlet-side portion (111). The provision of the outlet-side taper portion (115) with a small inclination angle prevents an increase in the resistance of flow of fuel in the direction from the common rail (3) toward a corresponding one of the fuel injection valves (10a-10d). The provision of the inlet-side taper portion (111) with a great inclination angle increases the fuel flow resistance due to pressure pulsation from the corresponding one of the fuel injection valves (10a-10d) toward the common rail.

FIG. 2



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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a fuel injection apparatus and, more particularly, to a fuel injection apparatus that distributes fuel from a pressure accumulating chamber (common rail) storing high-pressure fuel to individual fuel injection valves and that intermittently performs fuel injection from the fuel injection valves, for example, a common rail type fuel injection apparatus of an internal combustion engine.

2. Description of the Related Art

[0002] A common rail type fuel injection apparatus is known in which a pressure accumulating chamber (common rail) for storing high-pressure fuel is provided and the common rail is connected to individual fuel injection valves so as to distribute high-pressure fuel from the common rail to each fuel injection valve. In common rail type fuel injection apparatuses, the pressure in the common rail (i.e., pressure of injection from each fuel injection valve) can be kept at a desired value set in accordance with the state of operation of the engine by controlling the amount of fuel delivered from a high-pressure fuel pump to the common rail. Therefore, unlike conventional mechanical drive type fuel injection pumps (jerk type pumps) or the like, the common rail type fuel injection apparatuses are able to maintain high fuel injection pressure even during low-speed operation of the engine, and are able to accomplish good atomization of injected fuel even during low-speed engine operation, thereby achieving the advantage of improving the combustion state of the engine.

[0003] However, in the common rail type fuel injection apparatuses , fuel injection is performed at high pressure (e.g., 100 to 150 MPa), so that each fuel injection valve undergoes great pressure fluctuations at the start and end of fuel injection. Such pressure fluctuations propagate to the common rail via fuel supplying pipes connecting the fuel injection valves and the common rail, and are reflected in a complicated fashion, thereby fluctuating the injection pressure of the fuel injection valves. For example, if pressure fluctuations occurring in a fuel injection valve at the end of a fuel injection are reflected from the common rail, and return to the fuel injection valve, the pressure in the fuel supplying pipes pulsates despite the end of fuel injection, until the pressure fluctuations attenuate. Therefore, in a construction where pilot fuel injection is performed prior to main fuel injection in, for example, diesel engines and the like, the main fuel injection may be started before the pressure fluctuations in the fuel supplying pipe caused by the pilot fuel injection attenuate in some cases, so that the amount of injection of the main fuel injection and the injection timing thereof may become inaccurate.

[0004] Furthermore, since the individual fuel injection valves are connected to a single common rail, a pressure fluctuation caused by a fuel injection operation of a single fuel injection valve is reflected inside the common rail, and therefore affects the pressures in the fuel supplying pipes of the other fuel injection valves.

[0005] To prevent influences of the pressure fluctuation in each fuel injection valve, each of fuel supplying pipe connecting portions of the common rail to the individual fuel injection valves is provided with a flow passage area-reduced portion, as in an orifice or the like. Due to the passage resistance of each orifice, pressure pulsation is attenuated within a short period of time.

[0006] In order to attenuate the pressure pulsation within a short period of time, it is preferred to set as small an orifice diameter as possible. However, if the orifice diameter is set small, the resistance of the orifice becomes great, thus giving rise to a problem of reduction in the amount of flow of fuel from the common rail to each fuel injection valve. That is, the setting of the orifice diameter smaller than a certain diameter inconveniently reduces the injection pressure during fuel injection, thereby giving rise to a problem of a prolonged duration of fuel injection for injecting a needed amount of fuel. If it is intended to keep the injection pressure during fuel injection of each fuel injection valve at a sufficiently high value, the orifice diameter can be reduced only to a certain level, thereby giving rise to a problem of an insufficient attenuation of pressure pulsation becomes insufficient.

[0007] To solve this problem, Japanese Patent Application Laid-Open No. HEI 9-112380, as for example, proposes that fluidic diodes be disposed in fuel pipes connecting the common rail and the individual fuel injection valves. A fluidic diode described in Japanese Patent Application Laid-Open No. HEI 9-112380 has a large-diameter hole, a contracted pipe-like taper hole, an orifice hole that are continuously formed in that order from the common rail side to the fuel injection valve side. The fluidic diode described in the aforementioned laid-open application utilizes a phenomenon that fuel flowing from the common rail side toward the fuel injection valve side flows from the large-diameter hole into the orifice hole through the contracted pipe-like taper hole, and therefore undergoes a relatively small flow resistance whereas flows of fuel from the fuel injection valve side to the common rail side due to the pressure pulsation in each fuel injection valve directly flow into the orifice hole, and therefore undergo a relatively great flow resistance, so as to attenuate only the pressure pulsation within a short period of time without reducing the supply of fuel from the common rail to the fuel injection valves.

[0008] However, if fluidic diodes as described in the Japanese Patent Application Laid-Open No. HEI 9-112380 used, the flow resistance of fuel flowing from the common rail side to the fuel injection valve side is still a great value although the resistance slightly is

slightly less than the flow resistance with ordinary orifices. Therefore, even if fluidic diodes described in the laid-open patent application are incorporated, reduction of the orifice pore diameter for the purpose of sufficiently reducing the pressure pulsation results in insufficient fuel supply from the common rail side to the fuel injection valve side, thereby giving rise to a problem of reduction in the injection pressure during fuel injection.

SUMMARY OF THE INVENTION

[0009] The invention has been accomplished in view of the aforementioned problems. It is an object of the invention to provide a fuel injection apparatus that, when applied to a common rail type fuel injection apparatus, is able to maintain a sufficiently small resistance of flow of fuel from the common rail side to the fuel injection valve side and to sufficiently increase the resistance of flow of fuel from the fuel injection valve side to the common rail side.

[0010] In accordance with one mode of the invention, a fuel injection apparatus having a pressure accumulating chamber that stores a pressurized fuel, and a fuel injection valve that is connected to the pressure accumulating chamber and that injects the fuel supplied from the pressure accumulating chamber, includes: a constricted passage that is formed in the passage extending from the pressure accumulating chamber to the fuel injection valve and that has a passage sectional area that is smaller than an area of thc ejection opening; a tubular first taper portion that is connected to the constricted passage, and that is formed upstream of the constricted passage, and that tapers in a direction from the pressure accumulating chamber toward the constricted passage at a first predetermined inclination angle; and a tubular second taper portion that is connected to the constricted passage, and that is formed downstream of the constricted passage, and that tapers in a direction from the fuel injection valve toward the constricted passage at a second predetermined inclination angle. The second predetermined inclination angle (β) of the second taper portion is smaller than the first predetermined inclination angle (α) of the first taper portion.

[0011] That is, the fuel supplying passage is provided with a constriction, and a taper portion is formed at the inlet side (common rail side) of the constriction. Another taper portion is formed at the outlet side (fuel injection valve side) of the constriction. The inclination angle of a wall surface of the outlet-side taper portion (second taper portion) is set smaller than the inclination angle of a wall surface of the inlet-side taper portion (first taper portion).

[0012] If the flow passage is provided with a constriction, the flow resistance at the inlet side of the passage increases because the flow of fuel into the constriction encounters a sharp narrowing of the passage at the inlet of the constriction. The aforementioned related-art fluidic diode has a narrowed tube-like taper at the inlet of the passage wherein the flow resistance of fuel flowing into the constriction is reduced. In the related art, the outlet of the constriction is not provided with a taper portion. Therefore, as for the reverse flow (flow from the fuel injection valve toward the common rail), the flow into the constriction undergoes a sharp diameter reduction, thus increasing the flow resistance. That is, due to the provision of the taper only at the inlet side of the constriction, the fluidic diode achieves reduced resistance with respect to forward flow (flow from the common rail toward the fuel injection valve), and achieves increased resistance with respect to reverse flow (flow from the fuel injection valve toward the common rail).

[0013] However, the actual passage resistance of a fluid passing through a constriction greatly varies depending on the configuration of the outlet side of the constriction, as well as the configuration of the inlet side thereof. More specifically, if the passage sharply expands at the outlet side of the constriction, the sharp expansion of the passage causes greatly increased eddy loss, so that the passage resistance increases.

[0014] Therefore, if an outlet side of a constriction has a configuration with a discontinuous sharp expansion of passage even though the inlet side of a constriction has, as in the related art, a narrowed tube-like taper portion, the effect of a resistance increase caused by the sharp expansion of the outlet-side passage becomes more dominant than the effect of a passage resistance decrease caused by the provision of the taper portion at the inlet side. As a whole, the passage resistance of the constriction portion with respect to forward flow scarcely decreases in comparison with a construction in which the passage has only a constriction without a taper. Therefore, although the related art exhibits an effect of reducing the pressure pulsation due to increased passage resistance in the reverse direction (from the fuel injection valve toward the common rail), the related art hardly reduces the passage resistance of flow in the forward direction (from the common rail side to the fuel injection valve side) in comparison with a construction in which only a simple constriction is provided. Therefore, the related art still has a problem of insufficient fuel supply to a fuel injection valve during a fuel injection period.

[0015] In the invention, in contrast, a taper portion is provided at the outlet side of the constriction, as well as the inlet-side taper portion. Furthermore, the outlet-side taper portion is formed so that the inclination angle of the wall surface (inclination angle of the taper) of the outlet-side taper portion is smaller than that of the inlet-side taper portion. Thus, since the taper portion is provided at the outlet side of the constriction as well, loss caused by a sharp narrowing of passage at the inlet of the constriction with respect to forward flow does not occur. Furthermore, loss caused by a sharp expansion of passage at the outlet of the constriction does not occur, and the passage resistance with respect to flow in the forward direction considerably decreases in comparison with a construction in which only a simple constriction is

provided.

[0016] Furthermore, in this invention, the inclination angle of the taper at the inlet side of the constriction is greater than the inclination angle of the outlet-side taper. The constriction inlet-side taper functions as a constriction outlet-side taper with respect to flow in the reverse direction. However, if the inclination angle of the taper is great, the eddy loss caused by sharp passage expansion increases. As mentioned above, the constriction outlet-side taper is relatively gentle with respect to forward flow, so that there is no sharp passage expansion and the forward flow resistance becomes less. In contrast, the constriction inlet-side taper has a relatively great inclination, so that with respect to reverse flow, the sharp passage expansion at the outlet of the constriction increases the resistance. Therefore, according to the invention, the passage resistance with respect to flow in the forward direction of the fuel supplying passage (in the direction from the common rail toward the fuel injection valve) is considerably reduced, but the passage resistance with respect to flow in the reverse direction (in the direction from the fuel injection valve toward the common rail) is hardly reduced, in comparison with a construction in which only a simple constriction is provided.

[0017] Therefore, the flow caused in the reverse direction in the passage by pressure fluctuation due to injection from the fuel injection valve is blocked by the great resistance, whereas the flow in the forward direction in the passage does not receive resistance. Hence, in the invention, the pressure fluctuation caused by fuel injection attenuates within a short time, and at the same time, sufficient amount of fuel is supplied to the fuel injection valve during a fuel injection period so that the fuel injection pressure decrease during fuel injection period is eliminated.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] The foregoing and further objects, features and advantages of the present invention will become apparent from the following description of preferred embodiments with reference to the accompanying drawings, wherein like numerals are used to represent like elements and wherein:

FIG. 1 is a diagram schematically illustrating an overall construction of a fuel injection apparatus where the invention is applied to an automotive diesel engine;

FIG. 2 is a diagram illustrating the first embodiment of the invention;

FIG. 3 is a diagram illustrating a fuel passage in detail;

FIG. 4 is a diagram illustrating changes in the passage resistance in accordance with the expansion angle of the outlet-side taper portion;

FIG. 5 is a diagram illustrating changes in the fuel injection rate and the fuel pressure during a fuel injection period;

FIG. 6 is a diagram illustrating fluctuations in the amount of fuel injection with changes in the fuel injection internal at execution of the pilot fuel injection

FIG. 7 is a diagram illustrating a second embodiment of the invention;

FIG. 8 is a diagram illustrating a third embodiment of the invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0019] Preferred embodiments of the invention will be described hereinafter with reference to the accompanying drawings.

[0020] FIG. 1 is a diagram schematically illustrating a construction of an embodiment in which the fuel injection apparatus of the invention is applied to an automotive diesel engine.

[0021] In FIG. 1, an internal combustion engine 1 is a four-cylinder four-cycle diesel engine having four cylinders (#1 to #4). The internal combustion engine 1 is equipped with fuel injection valves (10a to 10d) for injecting fuel directly into the cylinders (#1 to #4). The fuel injection valves 10a-10d are connected to a common pressure accumulating chamber (common rail) 3 via high-pressure fuel pipes (fuel supply passages) 11a-11d. The common rail 3 has functions of storing pressurized fuel supplied from a high-pressure fuel injection pump 5, and distributing high-pressure fuel stored therein to the fuel injection valves 10a-10d via the high-pressure fuel pipes 11a-11d.

[0022] In this embodiment, the high-pressure fuel injection pump 5 is, for example, a plunger-type pump having a mechanism for adjusting the amount of ejection. The high-pressure fuel injection pump 5 pressurizes fuel supplied form a fuel tank (not shown) to a predetermined pressure, and supplies pressurized pressure to the common rail 3. The amount of fuel delivered from the pump 5 to the common rail 3 is feedback-controlled by an ECU 20 so that the pressure in the common rail 3 equals a target pressure. Therefore, the fuel pressure in the common rail 3 (i.e., the fuel injection pressure of the fuel injection valves) can be set to high pressure even during a low-speed engine operation. When a fuel injection valve 10a-10d opens, high-pressure fuel from the common rail 3 is injected into a corresponding one of the cylinders via the fuel injection valve. Since the capacity of the common rail 3 is far greater than the amount of fuel injected by one injecting operation, the fuel pressure in the common rail 3 (i.e., fuel injection pressure) is kept substantially constant during fuel injection durations of the fuel injection valves 10.

[0023] As shown in FIG. 1, the electronic control unit (ECU) 20 for controlling the engine is formed as a microcomputer having a known construction in which a read-only memory (ROM), a random access memory

(RAM), a microprocessor (CPU), and input/output ports are interconnected by a bidirectional bus. In this embodiment, the ECU 20 controls the amount of ejection from the pump 5 so to perform a fuel pressure control of controlling the common rail 3 pressure to a target value determined in accordance with an engine operation condition. Furthermore, the ECU 20 performs basic controls of the engine, such as a fuel injection control of controlling the fuel injection timing and the injection amount of main fuel injection by controlling the open valve timing and duration of the fuel injection valves 10a-10d, and the like.

[0024] To perform these controls, the common rail 3 in this embodiment is provided with a fuel pressure sensor 27 for detecting the common rail fuel pressure. Furthermore, an accelerator operation amount sensor 21 is provided near an accelerator pedal (not shown) of the engine 1 for detecting the amount of accelerator operation (the amount of depression of the accelerator pedal accomplished by an operating person). Still further, a cam angle sensor 23 for detecting the rotation phase of a camshaft of the engine 1, and a crank angle sensor 25 for detecting the rotation phase of a crankshaft are provided as shown in FIG. 1. The cam angle sensor 23 is disposed near the camshaft of the engine 1, and outputs a reference pulse at every 720 degrees in terms of crank rotation angle. The crank angle sensor 25 is disposed near the crankshaft of the engine 1, and outputs a crank angle pulse at every predetermined crank rotation angle (e.g., every 15 degrees).

[0025] The ECU 20 calculates the engine revolution speed from the frequency of the crank rotation angle pulse signal input from the crank angle sensor 25. Based on the engine revolution speed and the accelerator operation amount signal input from the accelerator operation amount sensor 21, the ECU 20 calculates the fuel injection timing and the fuel injection amount of each of the fuel injection valves 10a-10d.

[0026] During the fuel injection duration, when one of the fuel injection valves 10a-10d (hereinafter, collectively referred to as "fuel injection valves 10") opens, fuel flows into the fuel injection valve from the common rail 3 via a corresponding one of the high-pressure fuel pipes 11a-11d (hereinafter, collectively referred to as "high-pressure fuel pipes 11. When the fuel injection valve is closed upon the stop of the fuel injection, the flow of fuel is sharply discontinued, and the discontinuation of the flow produces pressure waves in the fuel injection valve. The pressure waves return to the common rail 3 via the high-pressure fuel pipe 11. Portions of the pressure waves propagate from the inside of the common rail 3 into the other high-pressure fuel pipes, and a portion of the pressure waves is reflected at the entrance of the common rail 3, and propagates back to the fuel injection valve 10. Therefore, when the fuel injection stops, reflected pressure waves fluctuate the fuel supplying pressure of the fuel injection valve.

[0027] In this embodiment, the above-described problem is solved by inserting an orifice piece 100 in each high-pressure fuel pipe 11 (more precisely, a connecting portion between each high-pressure fuel pipe 11 and the common rail 3) as shown in FIG. 2. The orifice piece 100 has a constriction that has taper portions at opposite sides.

[0028] As shown in FIG. 2, the orifice piece 100 is provided between the common rail 3 and the high-pressure fuel pipe 11. A fuel passage 3a is formed in the common rail 3. Since high-pressure fuel (e.g., about 100 to 150 MPa) is stored in the common rail 3, it is preferable in terms of strength of the common rail that a through-hole formed in the common rail 3 have a hole diameter that is reduced as much as possible. Therefore, in this embodiment, the diameter of the fuel passage 3a formed in a wall of the common rail is set to a small value. The fuel passage 3a also functions as a constriction in the fuel supplying path from the common rail to the fuel injection valve. In this embodiment, the orifice piece 100 is provided to prevent pressure fluctuation in the high-pressure fuel pipe 11. Therefore, there is no deed to cause the fuel passage 3a to function as a constriction. However, since the diameter of the fuel passage 3a of the common rail 3 is preferred to be small, a small-diameter passage is formed as the fuel passage 3a.

[0029] The orifice piece 100 in this embodiment has a small-diameter end 103 that is fitted into the high-pressure fuel pipe 11, and a large-diameter end 105 that is received by an orifice piece connecting portion of the common rail 3. The high-pressure fuel pipe 11 and the common rail 3 are firmly interconnected by a fitting (not shown), with the orifice piece 100 being disposed between the high-pressure fuel pipe 11 and the common rail 3.

[0030] The orifice piece 100 has a fuel passage 110 that is formed by an inlet-side taper portion 111, a small-diameter constricted portion 113, and an outlet-side taper portion 115.

[0031] FIG. 3 is an enlarged view illustrating the configuration of the fuel passage 110.

[0032] As shown in FIG. 3, the inlet-side taper portion 111 is formed at the inlet side (common rail side) of the small-diameter constricted portion 113. The inlet-side taper portion 111 has a taper tubular shape in which the bore gradually decreases in the forward flow direction (i.e., the direction from the common rail toward the fuel injection valve). In this embodiment, the inclination angle of the wall surface of the inlet-side taper portion 111 (the taper expansion angle indicated by α in FIG. 3) is set to at least 120 degrees.

[0033] The outlet-side taper portion 115 is formed on the outlet side (fuel injection valve side) of the small-diameter constricted portion 113. The outlet-side taper portion 115 has a taper tubular shape in which the bore gradually increases in the direction opposite to the forward flow direction. The inclination angle of the wall surface of the outlet-side taper portion 115 (indicated by β in FIG. 3) may be any angle in the range of $0 < \beta < 120$

degrees. The wall surface inclination angle of the outlet-side taper portion 115 is preferably 5 to 10 degrees and, more preferably, 7 to 8 degrees (about 7.5 degrees) as in the embodiment. The wall surface inclination angle of the outlet-side taper portion 115 is smaller than the wall surface inclination angle of the inlet-side taper portion 111.

[0034] Functions of the outlet-side taper portion 115 in this embodiment will next be described.

[0035] In a case where the outlet-side taper portion 115 is not provided, fuel flowing out of the small-diameter constricted portion 113 to the outlet side undergoes rapid expansion of the flow passage at the outlet of the small-diameter constricted portion 113, and therefore forms an eddy region around the outlet of the small-diameter constricted portion 113. Due to the formation of eddies, flow of fuel experiences a great pressure loss near the outlet of the small-diameter constricted portion 113. This pressure loss is considerably great. For example, the pressure loss substantially cancels out the pressure loss reducing effect achieved by the sharp diameter reduction of passage with respect to forward flow realized by the provision of the inlet-side taper portion 111. In contrast, if the outlet-side taper portion 115 is provided at the outlet of the small-diameter constricted portion 113 as shown in FIG. 3, the fuel passage gradually expands from the small-diameter constricted portion 113 to the high-pressure fuel pipe 11 via the inlet-side taper portion 111, so that the loss caused by sharp expansion of passage at the outlet is reduced.

[0036] However, the sharp passage expansion preventing effect of the outlet-side taper portion 115 varies in accordance with the expansion angle β the taper portion. FIG. 4 is a diagram illustrating changes in the pressure loss of flow of fuel through the outlet-side taper portion 115 where the expansion angle β of the outlet-side taper portion 115 is changed. As indicated in FIG. 4, the pressure loss increases as the expansion angle β is increased. However, within a range between, for example, β=0 (corresponding to a case where the outlet of the small-diameter constricted portion 113 is connected to a pipe having a diameter equal to the diameter of the outlet of the small-diameter constricted portion 113) and $\beta = \beta 1$, increases in the expansion angle β cause substantially no increase in the pressure loss. That is, if the expansion angle β is set equal to or less than $\beta 1$, the pressure loss hardly decreases from the loss occurring at $\beta = \beta 1$. If the expansion angle β exceeds $\beta 1$, increases in the expansion angle β relatively sharply increase the pressure loss. However, after the expansion angle β has reached $\beta 2$ ($\beta 2 > \beta 1$), further increases in the expansion angle β hardly increase the pressure loss. That is, if the expansion angle β is at least the angle $\beta 2$, the pressure loss with an outlet-side taper portion becomes substantially as great as the pressure loss without a taper portion (corresponding to β = 180 degrees).

[0037] Therefore, in this embodiment, the expansion angle of the outlet-side taper portion 115 is set to $\beta 1$ at which the pressure loss practically becomes a minimum. This angle has empirically been found to be about 7.5 degrees. This configuration practically minimizes the flow resistance of forward flow through the passage 110 of the orifice piece 100.

[0038] Furthermore, in the embodiment, the expansion angle α of the inlet-side taper portion 111 is set to a value that is equal to or greater than the value $\beta 2$. The value $\beta 2$ has been empirically found to be about 120 degrees. In this embodiment, the expansion angle α of the inlet-side taper portion 111 is set as in $\alpha \geq 120$ degrees ($\alpha < 180$ degrees). The purpose of setting the expansion angle of the inlet-side taper portion 111 to at least $\beta 2$ is to increase the pressure loss of flow through the passage 110 in the opposite direction (direction from the fuel injection valve side to the common rail side). That is, the inlet-side taper portion 111 avoids the sharp diameter reduction of passage and thereby reduces the pressure loss with respect to forward flow. With respect to reverse flow, the inlet-side taper portion 111 functions as an outlet-side taper portion, and increases the pressure loss. Namely, the pressure loss of reverse flow through the passage 110 is increased by setting an increased expansion angle α of the taper portion. More specifically, by setting the expansion angle α of the inlet-side taper portion 111 to at least 120 degrees, the pressure loss of reverse flow can be increased while the effect of reducing the pressure loss of forward flow is maintained.

[0039] Therefore, the orifice piece 100 of the embodiment produces the pressure loss due to the sharp passage expansion of the inlet-side taper portion 111 in addition to the pressure loss caused by the small-diameter constricted portion 113, with respect to flow through the passage 110 in the reverse direction (the direction from the fuel injection valve toward the common rail). Thus, the passage 110 provides great resistance with respect to reverse flow. With respect to forward flow through the passage 110, the inlet-side taper portion 111 reduces the pressure loss caused by the sharp diameter reduction of passage, and the outlet-side taper portion 115 considerably reduces the pressure loss caused by sharp passage expansion. Therefore, with respect to forward flow, the passage 110 causes only a small resistance that is about equal to the conduit resistance of the small-diameter constricted portion 113. Hence, the orifice piece 100 exhibits a characteristic in which the flow resistance is small with respect to forward flow, and is great with respect to reverse flow.

[0040] Therefore, if the orifice pieces of the embodiment are disposed between the common rail 3 and the fuel injection valves 10, reverse flows of fuel caused by pressure fluctuations are effectively attenuated, and pressure fluctuations are greatly attenuated. Furthermore, since the influence on forward flow of fuel is small, a sufficient amount of fuel is supplied to each fuel injection valve during the fuel injection period, so that decrease in the fuel injection pressure becomes unlikely

to occur.

[0041] FIGS. 5A and 5B illustrate effects of the orifice piece 100 of the embodiment based on experiment results.

[0042] FIG. 5A indicates changes in the fuel injection rate of a fuel injection valve 10 during a fuel injection period. FIG. 5B indicates changes in the fuel pressure at the inlet of a fuel injection valve during the same fuel injection period as in FIG. 5A. In FIGS. 5A and 5B, a curve I indicated by a one-dot chain line represents a case where the high-pressure fuel pipe 11 is not provided with a constriction (i.e., where only the fuel passage 3a extending through the wall of the common rail 3 is present as a small-diameter portion within the fuel supplying path), and a curve II indicated by a solid line represents a case where the orifice piece 100 of the embodiment is provided, and a curve III indicated by a broken line represents a case where the high-pressure fuel pipe is provided with only a constriction (only a small-diameter constriction without tapered end portions). In FIG. 5A, changes in the injection rate in the case of the high-pressure fuel pipe 11 without a constriction and changes in the injection rate in the case of the orifice piece 100 are substantially the same, and are indicated by the solid line. Furthermore, in FIGS. 5A and 5B, a point A indicates a fuel injection start time point (time at which the fuel injection valve opens), and a point B indicates a fuel injection end time point (time at which the fuel injection valve closes).

[0043] The case where the high-pressure fuel pipe 11 is not provided with a constriction (curve I) will be first be described. In this case, after the fuel injection valve is opened to start fuel injection (point A), the fuel injection rate sharply increases (FIG. 5A) whereas the fuel pressure at the inlet of the fuel injection valve decreases with the progress of fuel injection (FIG. 5B). After that, pressure pulsation occurs due to the start of the fuel injection. Then, fuel pressure rises (point C in FIG. 5B), and the fuel injection rate continues increasing (FIG. 5A). When the fuel injection valve closes (point B in FIGS. 5A and 5B), the fuel injection rate sharply falls (FIG. 5A). The fuel pressure sharply rises as the valve closes (FIG. 5B). After the fuel injection valve closes, fuel pressure pulsation occurs due to reflection of pressure waves caused by the valve closing operation (interval D in FIG. 5B).

[0044] In the case where the high-pressure fuel pipe 11 is provided only a constriction (curve III), the amplitude of pressure pulsation is considerably smaller than in the case where no constriction is provided (curve I). However, during a later half of the fuel injection period in this case, the great resistance by the constriction causes a reduced amount of fuel that flows into the fuel injection valve and therefore causes a reduced fuel pressure (FIG. 5B), in comparison with the case where no constriction is provided (curve I). Therefore, the fuel injection rate becomes lower (FIG. 5A).

[0045] In the case where the orifice piece 100 of the embodiment is disposed in the high-pressure fuel pipe 11 (curve II), the amount of fuel that flows into the fuel injection valve exhibits substantially no decrease during a later stage of the fuel injection period due to effect of provision of the outlet-side taper portion 115, in comparison with the case (curve I) where no constriction is provided. The fuel pressure exhibits only a slight decrease (FIG. 5B). Thus, the fuel injection rate changes substantially in the same manner as in the case (curve I) where no constriction is provided, and no reduced fuel injection rate is exhibited during the late stage of the fuel injection period. Furthermore, since the inlet-side taper portion 111 operates as a great resistance with respect to reverse flow as mentioned above, the amplitude of pressure pulsation after the end of fuel injection is reduced, and the pressure pulsation attenuates within a reduced time (FIG. 5B), in comparison with the case where no constriction is provided.

[0046] The pressure pulsation after fuel injection ends affects the amount of fuel injection and the injection timing of the next fuel injection in some cases as mentioned above. In a diesel engine that performs pilot fuel injection prior to main fuel injection, in particular, there are cases where the fuel pressure pulsation after the end of pilot fuel injection affects the injection amount and the injection timing of the subsequent main fuel injection. Therefore, the fuel pressure pulsation after fuel injection ends needs to be attenuated quickly.

[0047] FIGS. 6A and 6B are diagram illustrating the influences that pressure pulsation has on the amount of fuel injection in a case where pilot fuel injection is performed. FIG. 6A indicates pilot fuel injection of an amount Q1 of fuel and, after an interval T, main fuel injection of a predetermined length of time.
FIG. 6B indicates changes in the total fuel injection amount (i.e., the total amount Q1 + Q2 of the pilot fuel injection amount Q1 and the main fuel injection amount Q2) with changes in the internal T.

[0048] Since pilot fuel injection fluctuates the pressure in the inlet of the fuel injection valve as mentioned above, a change in the interval T changes the fuel injection pressure at the time of start of main fuel injection. Therefore, even if the main fuel injection period is fixed, the fuel injection amount fluctuates in accordance with the interval T.

[0049] In FIG. 6B, a curve I indicated by a one-dot chain line represents a case where the high-pressure fuel pipe 11 is not provided with a constriction, and a curve II indicated by a solid line represents a case where the orifice piece 100 of the embodiment is provided, and a curve III indicated by a broken line represents a case where the high-pressure fuel pipe is provided with only a constriction without tapered end portions, as in FIGS. 5A and 5B. As indicated in FIG. 6B, in the case (curve I) where no constriction is provided, the fuel pressure pulsation after pilot fuel injection ends is great, the width of fluctuations in the total fuel injection amount with changes in the interval T b comes a greatest. That is,

in the case (curve III) where only a constriction is provided and the case (curve II) where the orifice piece 100 is provided, the widths of fluctuations in the total fuel injection amount are less than in the case of the curve I. Therefore, it should be understood that the provision of the orifice piece 100 of the embodiment prevents reduction in the fuel injection rate during the fuel injection period (FIG. 5A), and reduces the fluctuations in the amount of fuel injection occurring with changes in the interval T between pilot fuel injection and main fuel injection, and thereby allows accurate fuel injection control.

[0050] Embodiments of the invention other than the foregoing embodiment will be described with reference to FIGS. 7 and 8. Although in the foregoing embodiment, the orifice pieces 100 are inserted in the connecting portions between the common rail 3 and the high-pressure fuel pipes 11, and are fixed via pipe fittings, an independent orifice piece 100 is not provided in the embodiments.

[0051] In FIG. 7, an inlet-side taper portion 111, a small-diameter constricted portion 113 and an outlet-side taper portion 115 are formed in the wall of a common rail 3. In FIG. 8, an inlet-side taper portion 111, a small-diameter constricted portion 113 and an outlet-side taper portion 115 are formed in a pipe fitting (union) 80 used to interconnect the common rail 3 and the high-pressure fuel pipe 11. In the embodiments of FIGS. 7 and 8, the taper expansion angles of the taper portions 111, 115 are set to the same values as in the embodiment shown in FIGS. 2 and 3. The embodiments shown in FIGS. 7 and 8 do not need a separate orifice piece 100, so that the number of component parts of the entire apparatus can be reduced, and the assembly process can be simplified.

[0052] According to the invention, the orifice piece 100 is inserted in a connecting portion between the common rail 3 and the high-pressure fuel pipe 11 for supplying fuel pressure from the common rail 3 to a fuel injection valve. The orifice piece has a fuel passage formed by the inlet-side taper portion 111, the small-diameter constricted portion 113 and the outlet-side taper portion 115. The inclination angle of the wall surface of the outlet-side taper portion is set smaller than the inclination angle of the wall surface of the inlet-side taper portion. The provision of the outlet-side taper portion with a small inclination angle prevents an increase in the resistance of flow of fuel in the direction from the common rail toward the fuel injection valve. The provision of the inlet-side taper portion with a large inclination angle increases the resistance of flow of fuel caused by pressure pulsation from the fuel injection valve toward the common rail.

[0053] When the invention is applied to a common rail type fuel injection apparatus, it becomes possible to maintain a sufficiently small resistance of flow of fuel from the common rail side to the fuel injection valve side, and to sufficiently increase the resistance of flow of fuel from the fuel injection valve side to the common rail side. Thus, the invention achieves an advantage of improving the precision of the fuel injection control.

[0054] While the present invention has been described with reference to what are presently considered to be preferred embodiments thereof, it is to be understood that the present invention is not limited to the disclosed embodiments or constructions. On the contrary, the present invention is intended to cover various modifications and equivalent arrangements.

[0055] Orifice pieces (100) are disposed in connecting portions between a common rail (3) and high-pressure fuel pipes (11) that supply high-pressure fuel to fuel injection valves (10a-10d). Each orifice piece (100) has, in its interior, a fuel passage that is formed by an inlet-side taper portion (111), a small-diameter constricted portion (113), and an outlet-side taper portion (115). The inclination angle of a wall surface of the outlet-side taper portion (115) is set smaller than the inclination angle of a wall surface of the inlet-side portion (111). The provision of the outlet-side taper portion (115) with a small inclination angle prevents an increase in the resistance of flow of fuel in the direction from the common rail (3) toward a corresponding one of the fuel injection valves (10a-10d). The provision of the inlet-side taper portion (111) with a great inclination angle increases the fuel flow resistance due to pressure pulsation from the corresponding one of the fuel injection valves (10a-10d) toward the common rail.

Claims

1. A fuel injection apparatus comprising:

   a pressure accumulating chamber (3) that stores a pressurized fuel and supplies the pressurized fuel via an ejection opening (105);
   a fuel injection valve (10a-10d) that receives the fuel supplied from the pressure accumulating chamber (3) via a passage (11) and that injects the fuel;
   a constricted passage (113) that is formed in the passage (11) extending from the pressure accumulating chamber (3) to the fuel injection valve (10a-10d) and that has a passage sectional area that is smaller than an area of the ejection opening (105);
   a tubular first taper portion (111) that is connected to the constricted passage (113), and that is formed upstream of said constricted passage (113), and that tapers in a direction from the pressure accumulating chamber (3) toward the constricted passage (113) at a first predetermined inclination angle (α); and
   a tubular second taper portion (115) that is connected to the constricted passage (113), and that is formed downstream of said constricted passage (113), and that tapers in a direction

from the fuel injection valve (10a-10d) toward the constricted passage (113) at a second predetermined inclination angle (β),
wherein the second predetermined inclination angle (β) of the second taper portion (115) is smaller than the first predetermined inclination angle (α) of the first taper portion (111).

2. A fuel injection apparatus according to claim 1, wherein an inclined surface of the second taper portion is formed so that a pressure loss that occurs in the fuel flowing from the constricted passage (113) to the fuel injection valve (10a-10d) is substantially equal both at an upstream side of the second taper portion and at a downstream side of the second taper portion.

3. A fuel injection apparatus according to claim 1 or 2,

   wherein the first predetermined inclination angle defined by an inclined surface that is formed symmetrically about a center axis of the passage is at least 120 degrees, and
   wherein the second predetermined inclination angle defined by an inclined surface that is formed symmetrically about the center axis of the passage is 7 to 8 degrees.

4. A fuel injection apparatus according to any one of claims 1 to 3, wherein a member (100) that integrally forms the first taper portion (111), the constricted passage (113) and the second taper portion (115) is disposed between the pressure accumulating chamber (3) and the passage (11) that conveys the fuel to the fuel injection valve (10a-10d).

5. A fuel injection apparatus according to claim 4, wherein the member (100) performs a function of a fitting for coupling the pressure accumulating chamber (3) and the passage (11).

6. A fuel injection apparatus according to any one of claims 1 to 3, wherein the first taper portion (111) connected to the ejection opening (105), the constricted passage (113), and the second taper portion (115) are formed within a wall that forms the pressure accumulating chamber (3).

FIG. 1

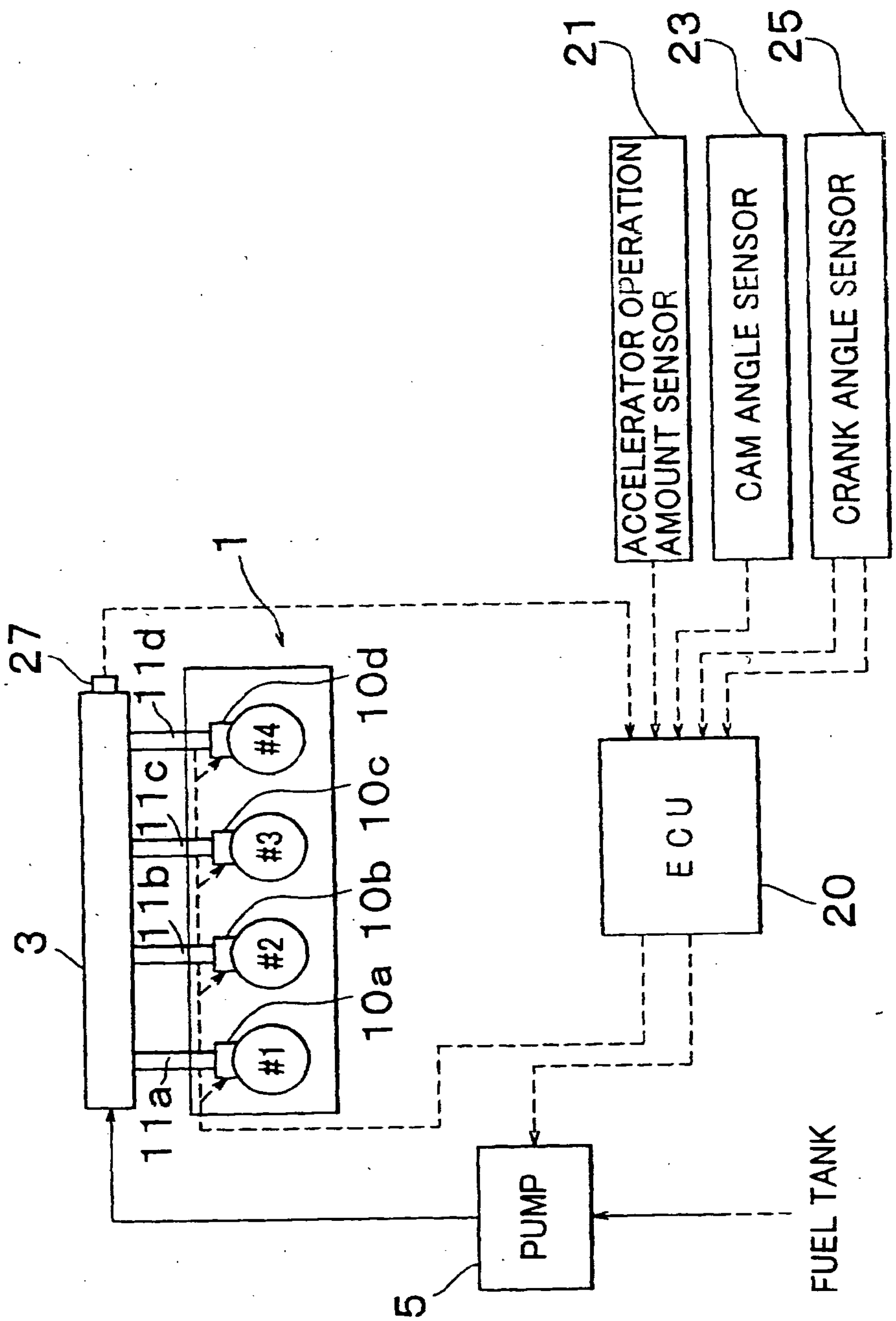

ACCELERATOR OPERATION AMOUNT SENSOR
CAM ANGLE SENSOR
CRANK ANGLE SENSOR
ECU
PUMP
FUEL TANK
#1
#2
#3
#4
21
23
25
20
27
1
3
5
11a
11b
11c
11d
10a
10b
10c
10d

FIG. 2

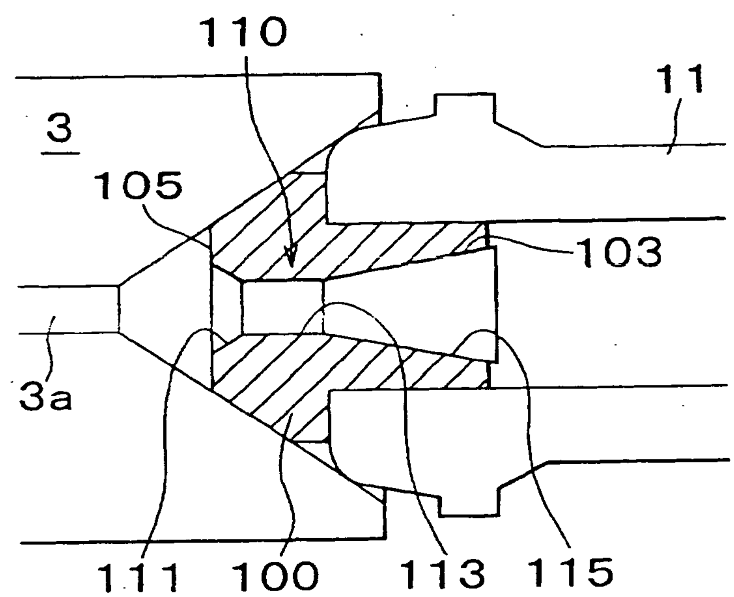


FIG. 3

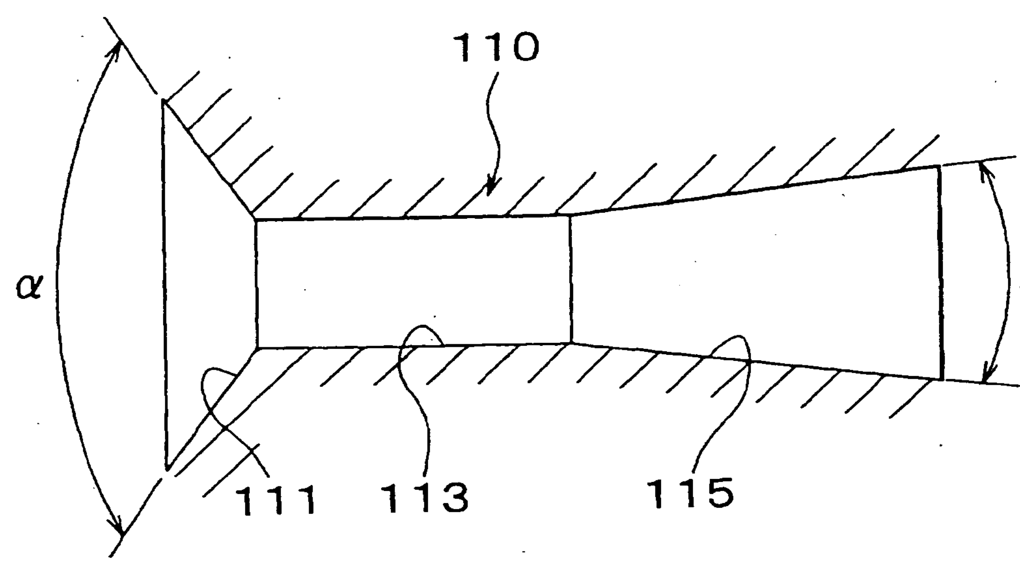
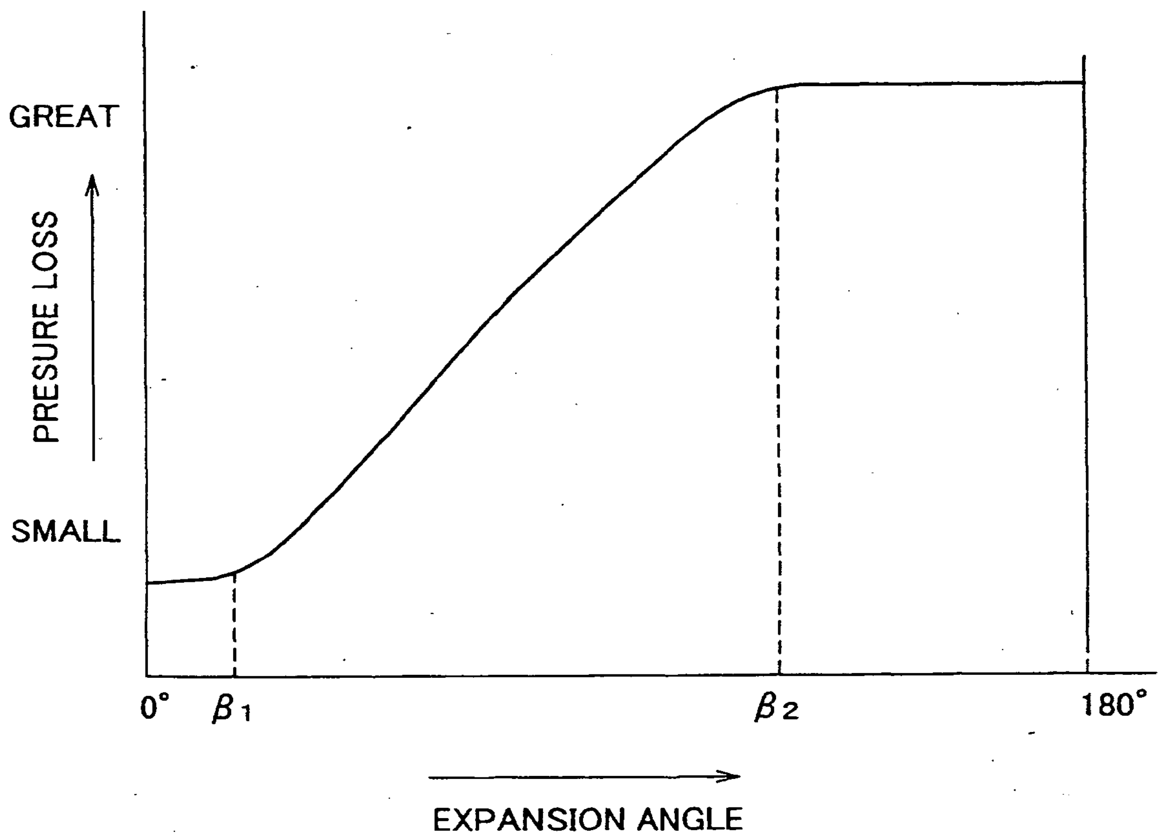


FIG. 4



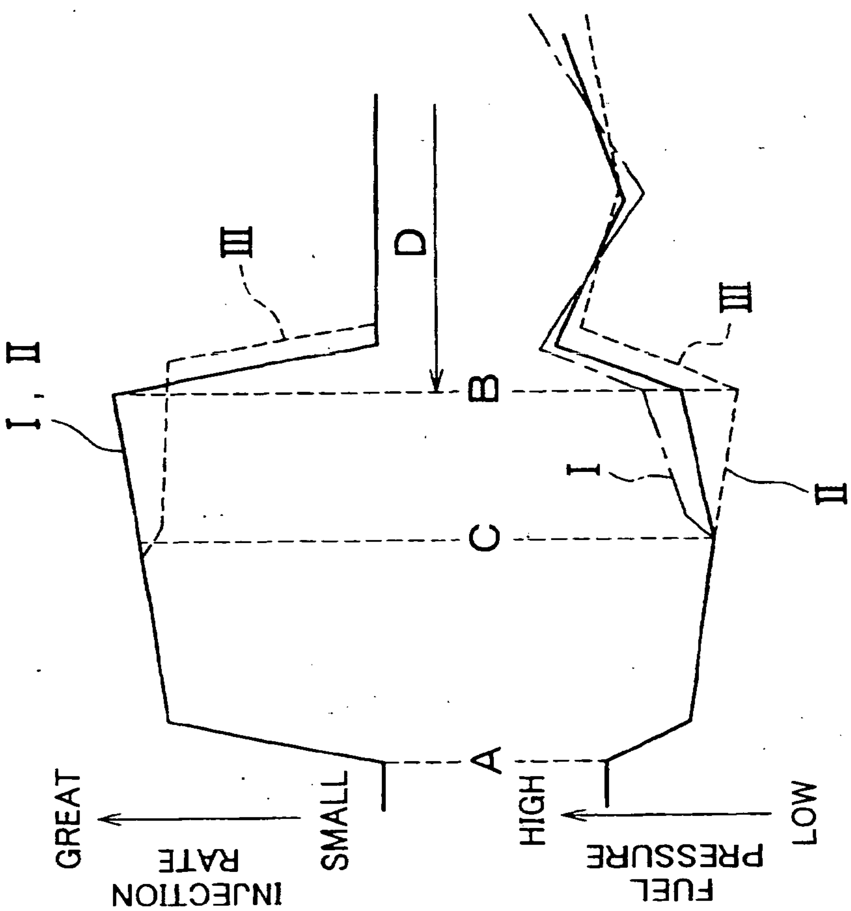

I, II
III
D
B
C
A
GREAT
INJECTION RATE
SMALL
HIGH
FUEL PRESSURE
LOW
III
I
II

FIG. 5A

FIG. 5B

FIG. 6A

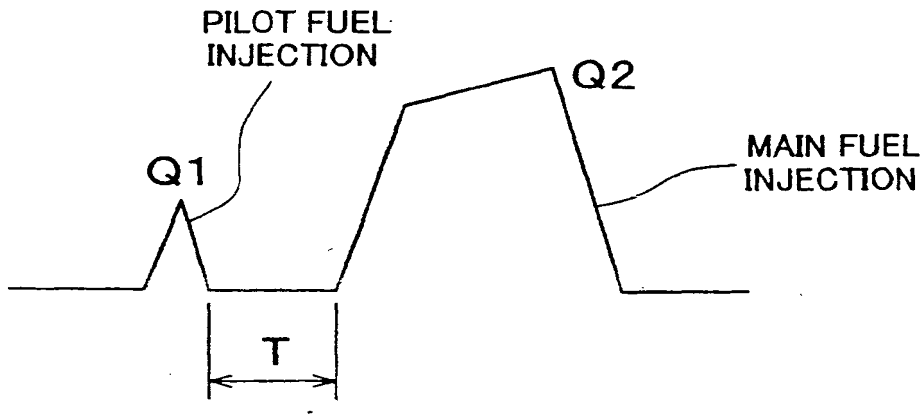

PILOT FUEL INJECTION
Q1
Q2
MAIN FUEL INJECTION
T

FIG. 6B

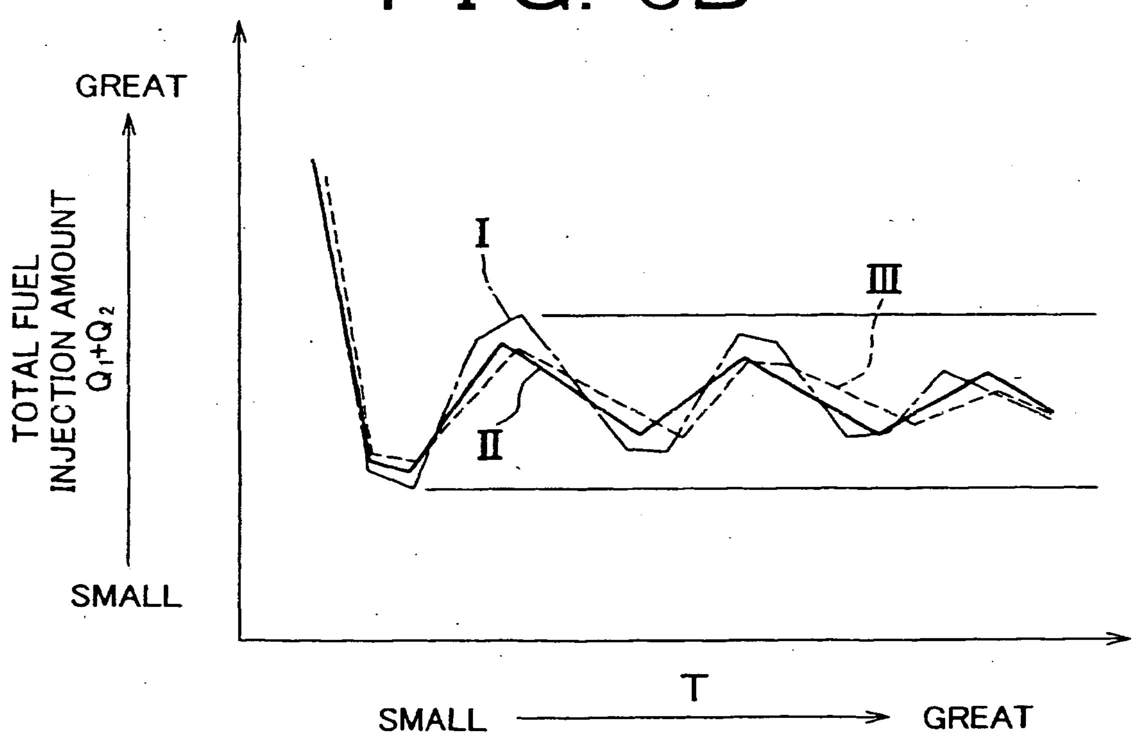

GREAT
TOTAL FUEL INJECTION AMOUNT Q_1+Q_2
SMALL
I
II
III
T
SMALL
GREAT

FIG. 7

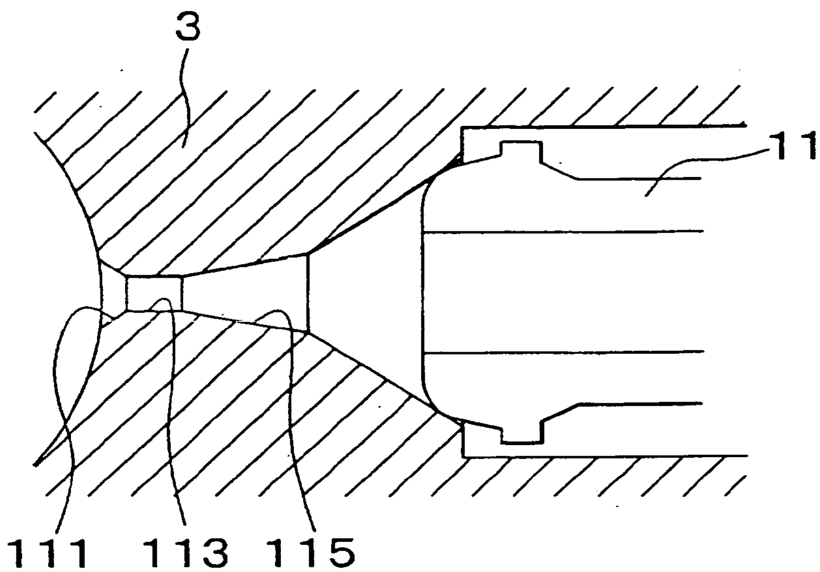
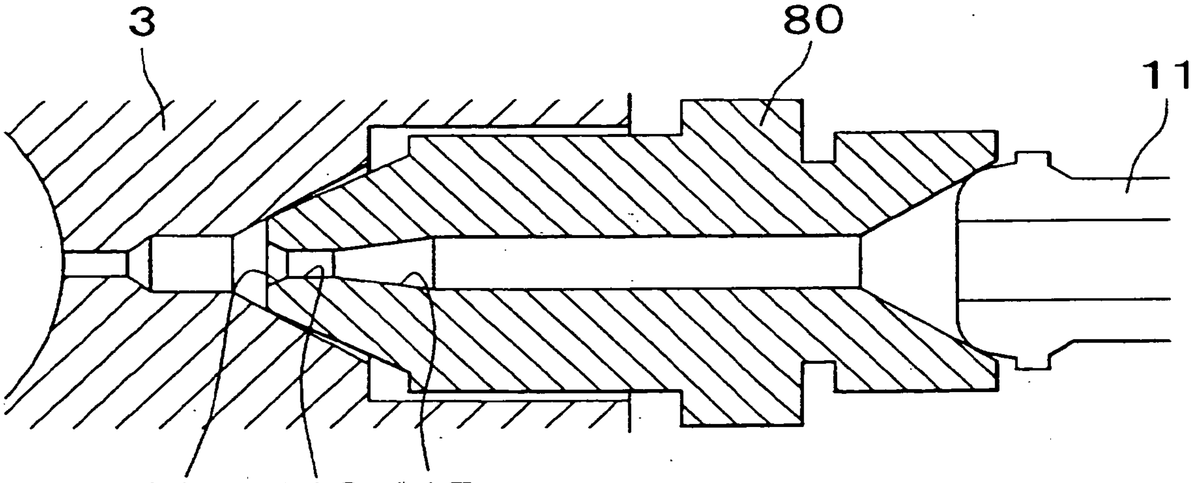


FIG. 8



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EUROPEAN SEARCH REPORT

Application Number
EP 01 11 3920

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
D,A	PATENT ABSTRACTS OF JAPAN vol. 1997, no. 08, 29 August 1997 (1997-08-29) & JP 09 112380 A (DENSO CORP), 28 April 1997 (1997-04-28) * abstract *	1,4,5	F02M55/02
A	US 4 356 091 A (NILES ALBERT B) 26 October 1982 (1982-10-26) * column 2, line 33 - line 54; figure *	1,4	
A	PATENT ABSTRACTS OF JAPAN vol. 1998, no. 03, 27 February 1998 (1998-02-27) & JP 09 303232 A (TOYOTA MOTOR CORP;TOYOTA AUTOM LOOM WORKS LTD), 25 November 1997 (1997-11-25) * abstract *	1,4,5	
A	US 5 903 964 A (KATO NOBUO ET AL) 18 May 1999 (1999-05-18) * column 3, line 1 - column 4, line 20; figures 1,2 *	1,6	TECHNICAL FIELDS SEARCHED (Int.Cl.7) F02M

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	12 October 2001	Hakhverdi, M

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12-10-2001

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
JP 09112380	A	28-04-1997	NONE		
US 4356091	A	26-10-1982	NONE		
JP 09303232	A	25-11-1997	NONE		
US 5903964	A	18-05-1999	JP	9317599 A	09-12-1997
			DE	19721175 A1	27-11-1997
			US	6186121 B1	13-02-2001

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